The Impact of Orthopedic Surgery on Gait Kinematics, Postural Balance, and Walking Speed in Children with Spastic Cerebral Palsy: A Multidimensional Approach

Abstract

Introduction: Spastic cerebral palsy (CP) is the most prevalent motor disability in children, defined by chronic spasticity, muscle stiffness, and motor control impairment, resulting in gait disturbances, postural instability, and decreased walking speed. Orthopedic surgery, including tendon lengthening and muscle releases, is routinely employed to rectify musculoskeletal deformities and enhance motor function. The extent to which these surgeries affect gait kinematics, postural balance, and walking speed is uncertain. The purpose of the current study was to assess the influence of orthopedic surgery on gait kinematics, postural balance, and gait speed in children with spastic CP via a multi-dimensional approach.

Materials & Methods: A prospective observational cohort study was carried out in 30 children (5–12 years, GMFCS Levels I–III) who were scheduled for orthopedic surgery. Participants were evaluated preoperatively and 6 and 12 months after surgery. Outcomes were gait kinematics (stride length, cadence, joint angles), postural balance (Pediatric Balance Scale [PBS], Timed Up and Go [TUG] test), and gait speed (10-Meter Walk Test [10MWT]). Data were analyzed using repeated-measures ANOVA, and effect sizes (Cohen's d) were determined.

Results & Discussion: At 12 months after surgery, there were significant improvements in all outcome measures. Stride length improved by 12.5% ($p < 0.01$), and cadence by 8.3% ($p < 0.05$). Knee flexion angle and ankle dorsiflexion angle also improved significantly ($p < 0.01$). Postural balance was improved, with PBS scores rising from 42.3 to 48.7 ($p < 0.01$) and TUG test times falling from 12.5 to 9.8 seconds ($p < 0.01$). Walking speed was enhanced by 18.6% in comfortable speed and 15.2% in fast speed ($p < 0.01$). Subgroup analysis showed greater improvement in children with GMFCS Level I compared to Levels II and III ($p < 0.05$). No differences were noted between tendon lengthening and muscle releases ($p > 0.05$).

Conclusion: Orthopedic surgery significantly improves gait kinematics, postural balance, and gait velocity in children with spastic CP, with the effects being preserved 12 months post-surgery. The findings emphasize the contribution of surgical interventions and personalized rehabilitation protocols in improving functional mobility and quality of life in these patients.

Keywords: Cerebral palsy, Orthopedic surgery, Gait.

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Introduction

The most common motor childhood disability is spastic cerebral palsy (CP), which is typified by chronic spasticity, stiffness of the muscles, and compromised motor control[(1)]. These neurologic impairments often result in serious gait deformities, postural instability, and slowed walking speed, substantially impacting the functional mobility and quality of life for these children[(2)]. Orthopedic surgical techniques, such as tendon lengthening, or muscle releases, are most often employed to correct musculoskeletal deformity and improve motor function [(3)]. However, the relationship among these operations and their influence on gait kinematics, postural balance, and walking speed is a focus of research[(4)].

Gait deviation in spastic CP children is typically defined by hyperextension of the knee, equines foot position, and internal rotation of the hip, leading to less efficient and energy-wasting gait patterns[(5)]. Postural balance, which is a significant component of functional mobility, is usually compromised by impaired proprioception and muscle coordination[(6)].

Walking speed, a functional measure of clinical concern, is also reduced in these children, further limiting engagement in activities of daily living[7]. Surgical interventions attempt to alleviate these impairments by correcting musculoskeletal alignment and reducing spasticity, but the extent to which these alterations are manifested in enhanced gait, balance, and walking speed is unclear[8].

Later work has focused attention on the potential benefits of orthopedic surgery to the correction of gait parameters and functional outcomes in children with spastic CP[9]. The data, though, are prone to be heterogenic, and with some investigations documenting large and meaningful gains in walking speed and balance, whereas others observe few or transitory changes[10]. The heterogeneity suggests that the analysis requires a multifaceted methodology with biomechanical, clinical, and functional evaluations in order to evaluate properly the impact of the surgical treatment[11,12].

This study seeks to fill the gap through examining the effect of orthopedic surgery on walking kinematics, balance posturing, and speed walking in spastic CP children.

We seek to provide a comprehensive understanding of how surgery influences these critical aspects. The findings of this study will not only contribute to the growing evidence base regarding the outcomes of surgery but also inform clinical decision, rehabilitation planning, and long-term care management of children with spastic CP.

Materials & Methods

Study Design

We employed a prospective, observational cohort design to examine the effect of orthopedic surgery on postural balance and walking speed in children with spastic cerebral palsy (CP). The participants were assessed at three time points: preoperatively (baseline), 6 months post-surgery, and 12 months post-surgery. The longitudinal design allowed for the evaluation of both short- and long-term outcomes following surgery.

Participants

Children aged 5–12 years with an established diagnosis of spastic hemiplegic and diplegic CP (GMFCS Levels I–III).

Scheduled for orthopedic intervention (tendon lengthening or muscle releases) as part of their treatment strategy.

Able to comprehend instructions and comply with them and willing to participate in gait and balance testing. Written informed assent from parent(s) or legal guardian(s).

Exclusion Criteria were included, profound cognitive or sensory impairment compromising testing, pre-existing orthopedic surgery during the previous 12 months, co-morbid conditions besides CP that could affect mobility.

30 participants were recruited from a tertiary pediatric rehabilitation clinic, and this gave a good representation of children with spastic CP.

Surgical Procedures

Tendon Lengthening, to address contractures of the Achilles tendon and hamstrings.

Muscle Releases (Fractional lengthening), to increase joint range of motion and alignment.

The surgical plan integrated both gait analysis (kinematic/kinetic parameters) and clinical examination (Modified Tardieu Scale for spasticity, passive range of motion). Achilles lengthening was prioritized for patients with >10° equinus in gait. Hamstring releases were performed if knee flexion >45° persisted in mid-stance.

All procedures were performed by an orthopedic surgeons and an occupational therapist specializing in cerebral palsy, with standardized postoperative protocols.

Outcome Measures

Gait Kinematics

Participants walked at a self-selected speed along a 10-meter walkway, with reflective markers placed over the major anatomical landmarks. Stride length, cadence, and joint angles were derived from the gait parameters through the use of motion capture technology.

Postural Balance

Assessed by standardized clinical tools, for example, the Pediatric Balance Scale (PBS) and the Timed Up and Go (TUG) test. The tools measured static and dynamic balance, and functional mobility.

Walking Speed

Quantified using the 10-Meter Walk Test (10MWT), where the subjects walked at their comfortable and fast speeds. Time was recorded using a stopwatch, and speed was calculated in meters per second (m/s).

Data Collection Procedure

Preoperative or baseline gait, balance, and walking speed measurements were taken 1–2 weeks before surgery.

Follow-up assessments were conducted 6 months and 12 months post-surgery.

All tests were administered by researchers and trained physiotherapists for consistency and reliability.

Data Analysis

Statistical Analysis

Descriptive statistics (mean, standard deviation) were computed to describe the participants' characteristics and outcome measures. Repeated-measures ANOVA was performed to compare the changes in gait parameters, balance, and walking speed across the three time points. Post-hoc tests with Bonferroni correction were conducted to identify the time points' significant differences. a p-value of <0.05 was considered statistically significant.

Effect Size Calculation

Effect sizes (Cohen's d) were calculated to determine the outcome measure changes' size, providing an understanding of the findings' clinical significance.

Ethical Considerations

Ethics Committee approval was obtained for the study from Mazandaran University of Medical Sciences' Emam Khomeini Hospital (Ethics Code: IR.MAZUMS.IMAMHOSPITAL.REC.1399.6937).

Written informed consent was obtained from parents or legal guardians, and assent was gained from children where feasible. All data were anonymized and stored securely to maintain participant confidentiality.

Results

Participant Characteristics

A total of 30 children with spastic cerebral palsy (CP) (GMFCS Levels I–III) were included in the study. The mean age of participants was 8.2 ± 2.1 years, with 16 males (53.3%) and 14 females (46.7%). The distribution of GMFCS levels was as follows: Level I (n = 12, 40%), Level II (n = 10, 33.3%), and Level III (n = 8, 26.7%). Diplegic, 22 patients (73.3%; 8 GMFCS I, 8 GMFCS II, 6 GMFCS III). Hemiplegic, 8 patients (26.7%; 4 GMFCS I, 2 GMFCS II, 2 GMFCS III). All the patients were treated with tendon lengthening (n = 18, 60%) and muscle releases (n = 12, 40%). (Table 1). 12 patients had Achilles tendon lengthening and 4 patients had hamstring lengthening.

Gait Kinematics

Improvements in gait parameters early in the course were observed postoperatively (Table 2). Stride length at 12 months post-surgery was elevated by 12.5% ($p < 0.01$) and cadence by 8.3% ($p < 0.05$) compared to baseline. All the joint angles, knee flexion, and ankle dorsiflexion were significantly improved ($p < 0.01$).

Table 1: Participant Demographics and Clinical Characteristics

Characteristic	Value (n = 30)
Age (years)	8.2 ± 2.1
Gender (Male, Female)	16, 14
GMFCS Level I	12 (40%)
GMFCS Level II	10 (33.3%)
GMFCS Level III	8 (26.7%)
Surgical Procedure	
- Tendon Lengthening	18 (60%)
- Muscle Releases	12 (40%)

Table 2: Changes in Gait Kinematics over Time

Parameter	Baseline	6 Months Post-op	12 Months Post-op	p-value
Stride Length (cm)	78.3 ± 6.2	84.5 ± 5.8	88.1 ± 6.0	<0.01
Cadence (steps/min)	102.4 ± 8.1	108.2 ± 7.5	110.9 ± 7.2	<0.05
Knee Flexion	42.5 ± 5.3	38.2 ± 4.8	36.0 ± 4.5	<0.01
Ankle Dorsiflexion	5.2 ± 2.1	8.5 ± 1.9	10.1 ± 1.8	<0.01

Postural Balance

Postural balance, measured through the Pediatric Balance Scale (PBS) and Timed Up and Go (TUG) test, improved notably over time (Table 3). Mean PBS score increased from 42.3 ± 4.1 at baseline to 48.7 ± 3.8 at 12 months after surgery ($p < 0.01$). Time on TUG test decreased from 12.5 ± 2.3 seconds at baseline to 9.8 ± 1.9 seconds at 12 months after surgery ($p < 0.01$).

Walking Speed

Walking speed, using the 10-Meter Walk Test (10MWT), demonstrated significant postoperative gains (Table 4). Fast comfortable walking speed improved by 18.6% ($p < 0.01$) and fast walking speed by 15.2% ($p < 0.01$) in comparison with preoperative at 12 months of surgery.

Effect Sizes

Effect sizes (Cohen's d) for improvement in the outcome measures were calculated to assess the magnitude of the improvements (Table 5). Large effect sizes for the improvements were observed for stride length (d = 1.2), PBS score (d = 1.5), and comfortable walking speed (d = 1.3), indicating clinically significant improvements.

Subgroup Analysis

Subgroup analysis at the levels of GMFCS showed that the children in GMFCS Level I demonstrated higher gains in gait speed and balance compared with the children with GMFCS Levels II and III ($p < 0.05$) (Table 6). However, there was considerable gait kinematic and functional improvement across all subgroups.

Comparison between Surgical Procedures

Comparison of results between muscle releases and tendon lengthening did not show differences ($p > 0.05$) (Table 7). There were no differences in outcome between the two operations for the correction of gait, balance, and walking speed.

Table 3: Changes in Postural Balance over Time

Measure	Baseline	6 Months Post-op	12 Months Post-op	p-value
PBS Score (0–56)	42.3 ± 4.1	46.2 ± 3.9	48.7 ± 3.8	<0.01
TUG Test (seconds)	12.5 ± 2.3	10.4 ± 2.1	9.8 ± 1.9	<0.01

Table 4: Changes in Walking Speed over Time

Parameter	Baseline	6 Months Post-op	12 Months Post-op	p-value
Comfortable Speed (m/s)	0.82 ± 0.15	0.94 ± 0.14	0.97 ± 0.13	<0.01
Fast Speed (m/s)	1.12 ± 0.18	1.25 ± 0.17	1.29 ± 0.16	<0.01

Table 5: Effect Sizes for Outcome Measures

Outcome Measure	Effect Size (Cohen's d)
Stride Length	1.2
Cadence	0.8
Knee Flexion	1.1
Ankle Dorsiflexion	1.4
PBS Score	1.5
TUG Test	1.3
Comfortable Walking Speed	1.3
Fast Walking Speed	1.1

Table 6: Subgroup Analysis by GMFCS Level

Outcome Measure	GMFCS Level I	GMFCS Level II	GMFCS Level III	p-value
Stride Length (cm)	90.2 ± 5.8	86.4 ± 6.1	83.5 ± 5.9	<0.05
PBS Score	50.1 ± 3.5	47.8 ± 3.7	45.2 ± 3.9	<0.05
Comfortable Speed (m/s)	1.02 ± 0.12	0.95 ± 0.14	0.89 ± 0.15	<0.05

Table 7: Comparison of Outcomes by Surgical Procedure			
Outcome Measure	Tendon Lengthening	Muscle Releases	p-value
Stride Length (cm)	87.5 ± 6.1	88.3 ± 5.9	>0.05
PBS Score	48.5 ± 3.7	48.9 ± 3.6	>0.05
Comfortable Speed (m/s)	0.96 ± 0.13	0.98 ± 0.12	>0.05

Discussion

The impact of orthopedic surgery on the postural balance, gait kinematics, and walking speed of children with spastic cerebral palsy (CP) was assessed in this study. The results demonstrate significant gains in all outcome measures at 6 and 12 months post-surgery, with the largest gains observed at the 12-month follow-up. These findings underscore the potential of orthopedic interventions, such as tendon lengthening and muscle releases, to enhance functional mobility and quality of life in children with spastic CP.

The gains noted in gait kinematics, including increased stride length, reduced knee flexion, and improved ankle dorsiflexion, align with previous studies reporting favorable results following orthopedic surgery in children with CP[13,14]. The 12.5% increase in stride length and 8.3% in cadence reflect surgical management to overcome musculoskeletal impairments leading to more energy-conserving and economical gait patterns[15]. These alterations are clinically relevant, as they indicate increased mobility and decreased energy cost of walking, which are essential for enhancing participation in activities of daily living[16].

The significant improvements in postural balance, as measured by the Pediatric Balance Scale (PBS) and Timed Up and Go (TUG) test, highlight the broader functional benefits of orthopedic surgery. The improvement in PBS scores from 42.3 to 48.7 points indicates better static and dynamic balance, while the reduction in TUG test time from 12.5 to 9.8 seconds indicates better functional mobility. These findings are consistent with studies citing the role of surgical intervention in enhancing postural control and reducing fall risk in children with CP[6]. The beneficial effects on balance can be attributed to better joint alignment and reduced spasticity, which facilitate more coordinated and stable movement[11].

The 18.6% improvement in comfortable walking speed and 15.2% improvement in fast walking speed at 12 months post-surgery are particularly noteworthy. Walking speed is a valuable indicator of functional capacity and is strongly related to participation in the community and quality of life[1]. The improvements observed demonstrate that orthopedic surgery not only enhances gait mechanics but leads to clinically significant mobility improvements in the everyday world as well. These findings are supported by previous research demonstrating similar improvements in walking speed following surgical interventions in children with CP[8,17].

The subgroup analysis revealed that children with GMFCS Level I improved more in walking speed and balance compared to children with GMFCS Levels II and III. This finding is consistent with the literature, which states that children with milder impairments (GMFCS Level I) have greater potential for functional gain due to their higher baseline mobility and motor control[10]. However, it is remarkable that all subgroups had significant improvements, underlining the importance of surgery along the spectrum of functional capacities.

No difference was detected between tendon lengthening and releases of the muscle in terms of outcomes. This means that the two operations have the same ability to improve gait, balance, and speed of walking among spastic CP children. The findings agree with a systematic review by McGinley et al[9], who did not establish any definite advantage of one procedure over the other. The choice of procedure can therefore be determined by the specific musculoskeletal impairments and clinical goals of each patient.

The findings of this study have important clinical implications. They first provide evidence that orthopedic surgery is a useful treatment for improving gait, balance, and walking speed in children with spastic CP. Second, the long-term benefits observed at 12 months post-surgery highlight the importance of ongoing postoperative rehabilitation to maximize the opportunity for functional gain. Third, subgroup analysis identifies the necessity for treatment protocols tailored to the functional status and specific needs of each child.

While this study is helpful, several caveats should be mentioned. First, sample size (n = 30) may limit the external validity of the findings. Second, the lack of a control group makes it impossible to separate the effect of surgery from natural increase or other therapies. Larger control group and sample size studies in the future would be needed to confirm these findings. Follow-up periods longer than 12 months would also provide more data about the durability of surgical outcomes.

Conclusion

This study demonstrates that orthopedic surgery enhances gait kinematics, postural balance, and walking speed in children with spastic CP substantially. The findings demonstrate the potential of surgical interventions to enhance functional mobility and quality of life in this population. Future research must address maximizing surgical techniques, postoperative rehabilitation protocols, and individualized treatment plans to further optimize outcomes in children with spastic CP.

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References

1 Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M. A report: The definition and classification of cerebral palsy April 2006. Dev Med Child Neurol Suppl. 2007;109:8–14. doi.org/10.1111/j.1469-8749.2007.tb12610.x
2 Graham HK, Rosenbaum P, Paneth N, et al. Cerebral palsy. Nat Rev Dis Primers. 2016;2:15082. doi.org/10.1038/nrdp.2015.82
3 Gough M, Shortland AP. Can clinical gait analysis guide the management of ambulant children with cerebral palsy? J Pediatr Orthop. 2012;32(Suppl 2):S1–S4. 10.1097/BPO.0b013e31818e197c
4 Thompson N, Stebbins J, Seniorou M, Newham D. The use of gait analysis in the treatment of cerebral palsy. J Pediatr Orthop. 2018;38(5):e1–e6, doi.org/10.1302/2058-5241.1.000052
5 Wren TA, Rethlefsen S, Kay RM. Prevalence of specific gait abnormalities in children with cerebral palsy: Influence of cerebral palsy subtype, age, and previous surgery. J Pediatr Orthop. 2005;25(1):79–83. doi.org/10.1097/00004694-200501000-00018
6 Rutz E, Hofmann E, Brunner R. Preoperative botulinum toxin test injections in children with cerebral palsy considering single event multilevel surgery. Dev Med Child Neurol. 2013;55(9):774–779. doi.org/10.1007/s00776-010-1509-6
7 Novacheck TF, Stout JL, Tervo R. Reliability and validity of the Gillette Functional Assessment Questionnaire as an outcome measure in children with walking disabilities. J Pediatr Orthop. 2000;20(1):75–81. doi.org/10.1097/01241398-200001000-00017
8 Dreher T, Wolf SI, Maier M, et al. Long-term results after gastrocnemius-soleus intramuscular aponeurotic recession as a part of multilevel surgery in spastic diplegic cerebral palsy. J Bone Joint Surg Am. 2012;94(7):627–637. doi.org/10.2106/jbjs.k.00096
9 McGinley JL, Dobson F, Ganeshalingam R, Shore BJ, Rutz E, Graham HK. Single-event multilevel surgery for children with cerebral palsy: A systematic review. Dev Med Child Neurol. 2012;54(2):117–128. doi.org/10.1111/j.1469-8749.2011.04143.x
10 Novak I, McIntyre S, Morgan C, et al. A systematic review of interventions for children with cerebral palsy: State of the evidence. Dev Med Child Neurol. 2013;55(10):885–910. doi.org/10.1111/dmcn.12246
11 Thomason P, Selber P, Graham HK. Single event multilevel surgery in children with bilateral spastic cerebral palsy: A 5-year prospective cohort study. Gait Posture. 2013;37(1):23–28. doi.org/10.1016/j.gaitpost.2012.05.022
12 Papageorgiou E, Nieuwenhuys A, Vandekerckhove I, et al. Systematic review on gait classifications in children with cerebral palsy: An update. Gait Posture. 2019;69:209–223. doi.org/10.1016/j.gaitpost.2019.01.038
13 Gage JR, Novacheck TF. An update on the treatment of gait problems in cerebral palsy. J Pediatr Orthop B. 2001;10(4):265–274. doi.org/10.1097/01202412-200110040-00001
14 Desloovere K, Molenaers G, Feys H, Huenaerts C, Callewaert B, Van de Walle P. Do dynamic and static clinical measurements correlate with gait analysis parameters in children with cerebral palsy? Gait Posture. 2006;24(3):302–313. doi.org/10.1016/j.gaitpost.2005.10.008
15 Rodda JM, Graham HK, Carson L, Galea MP, Wolfe R. Sagittal gait patterns in spastic diplegia. J Bone Joint Surg Br. 2004;86(2):251–258. doi.org/10.1302/0301-620x.86b2.13878
16 Bell KJ, Õunpuu S, DeLuca PA, Romness MJ. Natural progression of gait in children with cerebral palsy. J Pediatr Orthop. 2002;22(5):677–682. doi.org/10.1097/01241398-200209000-00020
17 Wren TA, Rethlefsen S, Kay RM. Prevalence of specific gait abnormalities in children with cerebral palsy: Influence of cerebral palsy subtype, age, and previous surgery. J Pediatr Orthop. 2005;25(1):79–83. doi.org/10.1097/00004694-200501000-00018